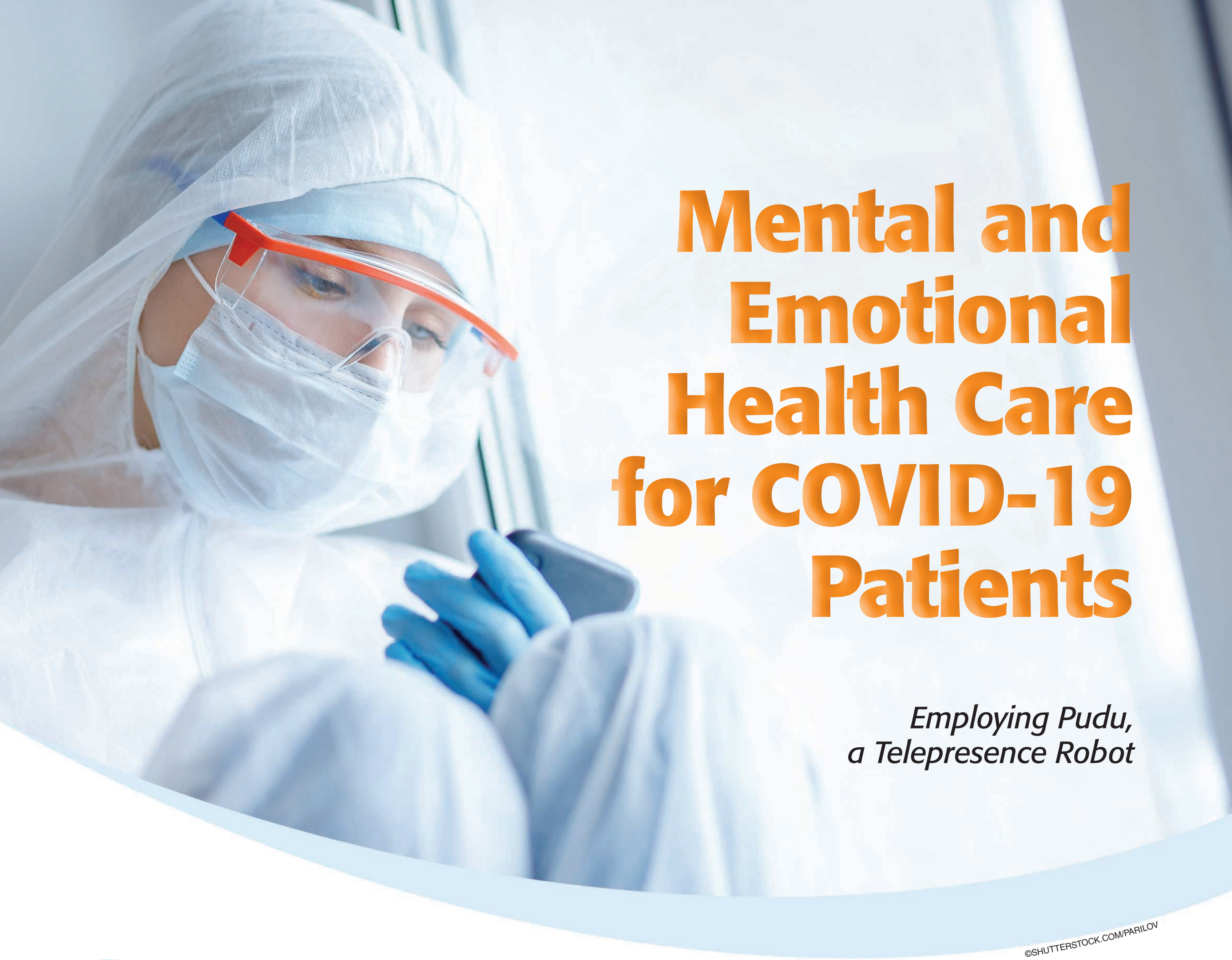

Mental and Emotional Health Care for COVID-19 Patients

Employing Pudu, a Telepresence Robot

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The COVID-19 pandemic is affecting the mental and emotional health of patients, family members, health-care workers, and the community. Patients are affected by symptoms produced by prolonged hospitalization and isolation, and health-care workers are affected by the stress produced by the possibility of infection and rapid changes in the kinds of care they provide. Robotics technologies can contribute to addressing these stresses. This article describes the development and main characteristics of Pudu, a telepresence robot designed to provide safe communication between COVID-19 patients and health-care workers, particularly neurologists and intensive care psychologists. The article identifies the key aspects that enabled the development and deployment of the robot in just eight weeks during an intensive quarantine and describes how the robot is assisting health-care workers in providing mental and psychological health care. At present, two Pudu robots are in use in two Chilean hospitals. Although the city of Santiago is moving toward less-intensive levels of quarantine, our robots are still needed to help provide the required emotional support and mental/psychological health care to confined patients.

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Background

The COVID-19 pandemic has impacted all health areas. In particular, as noted in the opening, it is affecting the mental health of patients, family members, health-care workers, and the community. Research in this regard, such as that reported in [1], shows a 56% increase in generalized anxiety disorders and an increase of more than 30% in major depressive disorders in patients infected with COVID-19. Health-care workers have also been significantly affected in emotional areas, as highlighted in several published studies [1]–[4], which show that approximately 35% have anxiety symptoms, 20% are afflicted with depressive symptoms,

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21–32% have sleep disorders, and 18% exhibit posttraumatic stress disorders. The previously mentioned studies suggest a postpandemic scenario in which emotional and mental health care will play a fundamental role, not only at the care level but also at the social and relationship levels. Consequently, acting right now is crucial for reducing the wave of mental health pathologies that will occur in the near future.

Robotics technologies can contribute to addressing these problems. In particular, new and safe ways of communication between confined COVID-19 patients and health-care workers as well as with their families are needed. There is significant evidence worldwide on the positive use of robotics in health-related actions, such as interventions and the health-care and therapeutic tasks associated with diagnostic and decision-making support [5]–[10]. From November 2019 to date, the use of robots for teleassistance has increased worldwide, which shows that this could be an invaluable solution to the problem of providing care to patients in isolation. Using robots to provide mental and emotional health care represents a major leap forward in the quantity, quality, and safety of patient care during the pandemic.

In Chile during the pandemic, gaining access to telepresence robots was not only difficult; it was nearly impossible because of their scarcity worldwide. For this reason, we decided to develop our own robots to be used specifically as tools for providing emotional and mental care to confined COVID-19 patients.

The research work described in this article met the requirements of neurologists and intensive care psychologists (psychointensivists) working in intensive care units (ICUs) in two Chilean hospitals where a safe method of communication between COVID-19 patients and the health-care workers responsible for providing them with emotional and mental care was needed. As in most countries suffering from the COVID-19 pandemic, in these hospitals, COVID-19 patients were in isolation, and the only way of communicating with them to provide care was through personal interactions or by using cellphones and tablets, also the means by which patients can have social communication with friends and family members. The main drawback of using these devices is the need for an uninfected person to handle and then pass the device to the patient, which requires that he or she dress in protective clothing before every patient interaction and to remove this clothing following each interaction. The process is time-consuming and requires the use of safety protective equipment (e.g., face shields) and consumables (e.g., gloves). After using them, the consumables are thrown out, which has economic and environmental impacts because most consumables are made of plastic.

The first step was to set up a project team composed of neurologists, psychointensivists, engineers, and designers who defined the basic requirements for a telepresence robot able to communicate with isolated patients. Then, a development team composed mainly of undergraduate and graduate engineering students with experience in robot development was formed. After eight weeks of hard work, the Pudu robot was designed, built, tested, and deployed in a hospital (see Figure 1), with all of the required permissions obtained. During that whole period, health and engineering professionals built an interdisciplinary team with all of its members working very closely during different stages of the project.

Using robots to provide mental and emotional health care represents a major leap forward in the quantity, quality, and safety of patient care during the pandemic.

The whole design, development, and testing process was developed during an intensive quarantine in the city of Santiago, which imposed several restrictions on travel within the city, the use of laboratories, the purchase of materials and devices, and field trials in hospitals. However, the high commitment of students—most of whom are members of our IEEE Robotics and Automation Society (RAS) Student Branch Chapter (SBC), who were taking online classes for their fall semester at the same time—made it possible to develop the project successfully. The other key factor for its success was the close interaction among neurologists and psychointensivists, who knew the specific needs to be fulfilled, and with the engineering team, which provided the technical solutions.

Currently, two Pudu robots have been in use in two Chilean hospitals for a little more than five months, during which time Santiago was under quarantine for the

(a) (b)

Figure 1. Pudu interacting with COVID-19 patients (a) when entering a room and (b) during a health-care session.

first two months. Our robots have been helping provide badly needed supportive care to patients isolated in ICUs.

The Design and Development Process

The main design requirements for the robot were simplicity and high usability (i.e., easy operation) by health-care workers, with the capability to be operated, handled, and transported by a single person. Moreover, the robot needed to be designed, developed, and built at a low cost, in a development time frame of just a few weeks. In addition, as it was not possible to have advance access to either accurate maps of the hospitals where the robot would operate or accurate location of patients' beds, the alternative of having autonomous operation was discarded, and it was decided to design a robot that operates in an assistive teleoperation mode [11] based on off-the-shelf devices.

Pudu is a social robot specifically designed to provide communication and telepresence services to COVID-19 patients.


(a) (b)

Figure 2. Pudu's first visit to the hospital. (a) Pudu entering an elevator and (b) moving in a corridor.

Table 1. Pudu's technical specifications.

Height	1,300 mm
Footprint	Circular, with a diameter of 456 mm
Weight	10 Kg
Mobile platform	Kobuki [13]
Main processing unit	Raspberry Pi 4 Model B 4 GB [14]
RGB-D camera	Intel RealSense D435i
Servocontroller	Arduino Nano
Servomotor	MG996R Servo Motor
Tablet	Samsung Galaxy Tab A10.1
Joystick	Xbox 360 Joystick

The design and development process implemented was essential for having a final version of the robot ready to be used in a hospital with all of the required permissions in just eight weeks. This process consisted of the following four stages.

1) *Stage 1—first design*: The first version of the robot was the result of addressing the first requirements of the health team. This development process was carried out in our fabrication laboratory, where it took four weeks. This rapid design was possible only because of the experience of the students' team in the RoboCup@Home competitions [12], where they acquired experience in designing and building robots.
2) *Stage 2—basic validation in the hospital*: A first visit to the hospital with the working prototype was carried out (see Figure 2). During this visit, the way in which the robot interacted with the hospital's infrastructure (corridors, lifts, care rooms, beds, and so on) was analyzed. In addition, the hospital's Department of Healthcare and Associated Infections (HAI) examined the robot and defined the requirements for its future operation in the hospital. We then took it back to the laboratory, and a second version of the robot was ready after one week.
3) *Stage 3—first interaction with patients*: A visit with the second version of the robot was carried out. During this visit, the robot was operated by a psychointensivist, and it interacted with patients. The experience was very successful, as the psychointensivist and patients were satisfied and pleased with the encounter, but two other requirements arose: the need to control the tilt angle of the camera for proper interaction with patients lying or sitting in different positions and the need for microphones with noise cancellation to filter out the noise generated by equipment used in ICUs. We again took the robot back to the laboratory, and after two weeks, had our third prototype.
4) *Stage 4—final validation*: A final validation was carried out on a third visit. During this visit, the robot was inspected, and we received final approval from both the HAI department and the ethics committee to use the robot inside the hospital. As a consequence of this visit, the hospital created and approved a formal protocol for the use of Pudu with patients (see the "Deployment and Early Results" section). In addition, the visit was used to calibrate—based on real interactions of the robot with health-care professionals and hospital furniture—the final position and tilt angle of the red, green, blue, depth (RGB-D) camera, which acquires the range data required for assistive teleoperation. After that, adjustments were made, and the final version of the Pudu robot was ready to be used.

Pudu—A Social Robot for Patient Communication and Telepresence

General Description: Hardware and Software Components

Pudu is a social robot specifically designed to provide communication and telepresence services to COVID-19 patients.

The robot is simple to use, inexpensive, and is based on off-the-shelf devices. Given that the robot weighs just 10 kg and has two handles on its base, it can be operated and transported by a single person (see Figures 1 and 2). The robot specifications are listed in Table 1.

The robot works by using an assistive teleoperation mode. The teleoperation commands are provided via an Xbox joystick, which allows for remotely controlling the robot's movements as well as the tilt angle of the tablet computer that communicates with the patient. The robot's mobility is provided by a Kobuki platform, a low-cost mobile base used for robot development (see the technical specifications in [13]). The tablet computer provides direct communication between the robot and the person standing in a different room or building, using either a wireless or 4G cellular network.

A Raspberry Pi 4 [14] acts as a central processing unit (see Figure 3). It is in charge of receiving the user's commands, processing the images acquired by an RGB-D camera (see the specifications in Table 1), and sending the control orders (speed commands) to the Kobuki platform and the tilt angles to an Arduino Nano. The Arduino Nano is connected to the servomotor in charge of controlling the tilt angle of the tablet computer. The Raspberry Pi 4 is also in charge of providing the robot's basic status to the user (battery charge, operation mode, and so forth).

Any piece of equipment, particularly a robot that interacts with isolated COVID-19 patients, should be sanitizable in a safe and rapid way.

The whole control software running on the Raspberry Pi 4 is based on the Robot Operating System (ROS) (see Figure 4). Most of the functionalities are provided by ROS packages (Melodic distribution) [15], which allow for acquiring the depth images (*realsense2_camera*), processing them (*depth_image_proc*), and transforming them to a

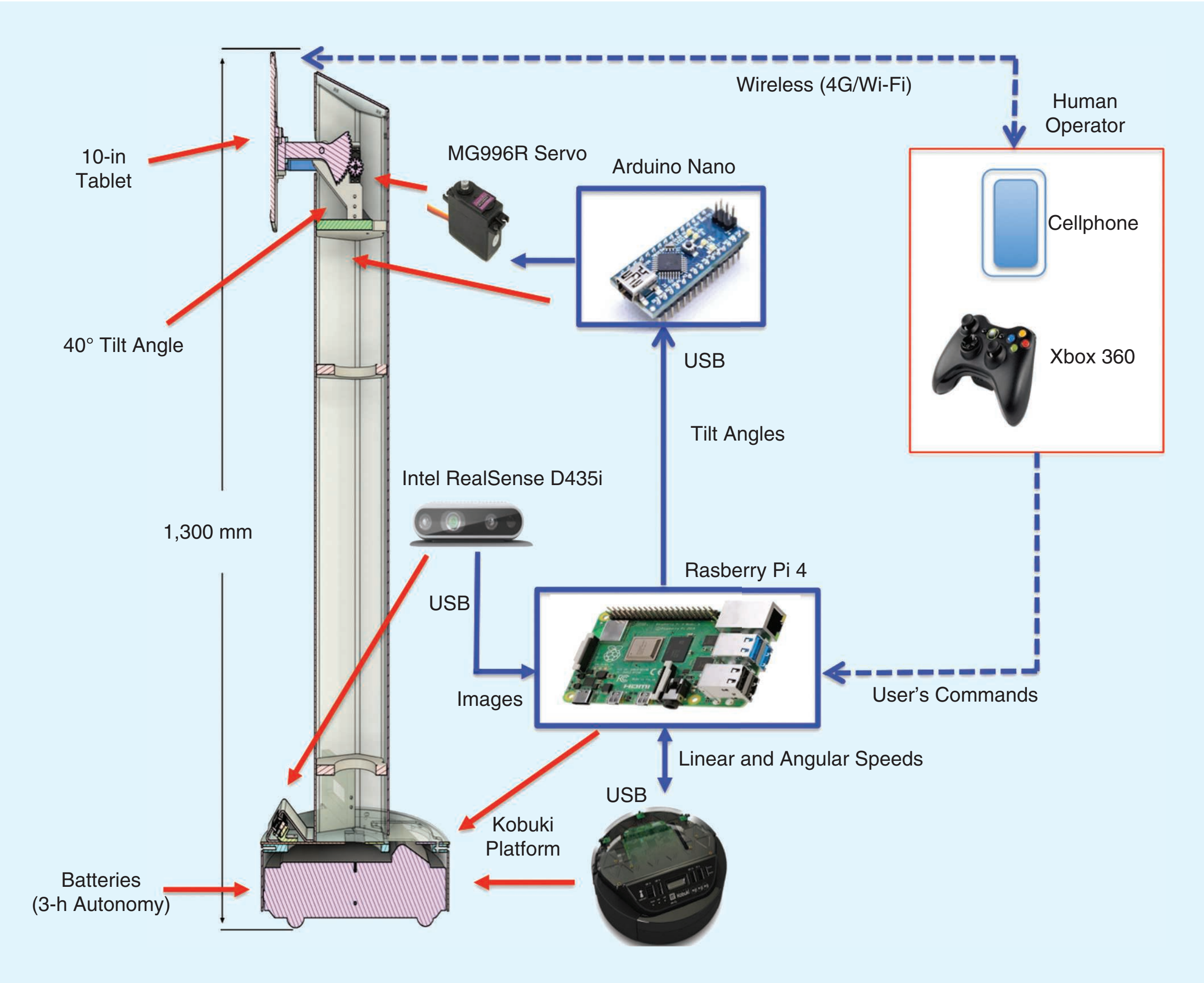

Figure 3. The main off-the-shelf devices used by Pudu and how they are integrated. USB: Universal Serial Bus.

laser scan format (*pointcloud_to_laserscan*); reading the joystick commands (*joy*), interpreting them as speed commands, and applying speed and acceleration limits to them (*yocs_velocity_smoother*); and connecting the Raspberry Pi 4 with the Kobuki platform (*kobuki_node*) and the Arduino Nano (*rosserial*).

Assistive Teleoperation

Assistive teleoperation is implemented by the safety layer module (see Figure 4), which controls the robot's linear speed to avoid collisions. The robot's angular speed is never limited, given the robot's circular footprint.

The module takes the laser scan generated by the *pointcloud_to_laserscan* as input and determines the distance to the closest obstacle in the direction of the robot's movement, $d_{\min}$. This distance is compared with two predefined safety thresholds: $d_{\max}^{\text{safety}}$, which determines the distance at which the safety module should start modifying the robot's linear speed, and $d_{\min}^{\text{safety}}$, which defines the distance at which the robot must stop. Then, the robot's linear speed is modified as

$$v_{\text{linear}}^{\text{out}} = \begin{cases} v_{\text{linear}}^{\text{in}} & \text{if } d_{\min} > d_{\max}^{\text{safety}}, \\ 0 & \text{if } d_{\min} < d_{\min}^{\text{safety}}, \\ v_{\text{linear}}^{\text{in}} \left(\dfrac{d_{\min} - d_{\min}^{\text{safety}}}{d_{\max}^{\text{safety}} - d_{\min}^{\text{safety}}} \right) & \text{otherwise.} \end{cases} \quad (1)$$

For situations in which the robot needs to move in restricted spaces (e.g., between very close beds), the user can choose, remotely, to deactivate the safety layer module. The speed commands *mux* module implements this multiplexing.

External Body and Sanitization Requirements

Any piece of equipment, particularly a robot that interacts with isolated COVID-19 patients, should be sanitizable in a safe and rapid way. Otherwise, the robot becomes a propagating agent of the virus. This requirement was taken into account in the design of Pudu's external body.

Pudu's body consists of a cylindrically shaped base, a post connecting the base and the tablet computer, and two handles used to lift the robot (see Figures 1, 2, and 5). The body is composed mainly of smooth surfaces. The materials used to build the body fulfill the health requirements. The external parts are built using aluminum composite plates, which are resistant to the cleaning products used in hospitals and are not penetrable by water [according to the American Society for Testing and Materials (ASTM) test method E331-00 (R2016)]. The two handles are made of high-density polyethylene, which is resistant to alcohols and acidic and alkaline elements but is less resistant to chlorinated solvents. This material is also impermeable to water [according to ASTM D570 (2)].

Deployment and Early Results

Since August 2020, Pudu robots have been used in two hospitals in the Santiago Metropolitan Region: the first was the Clinical Hospital of the University of Chile; the second was

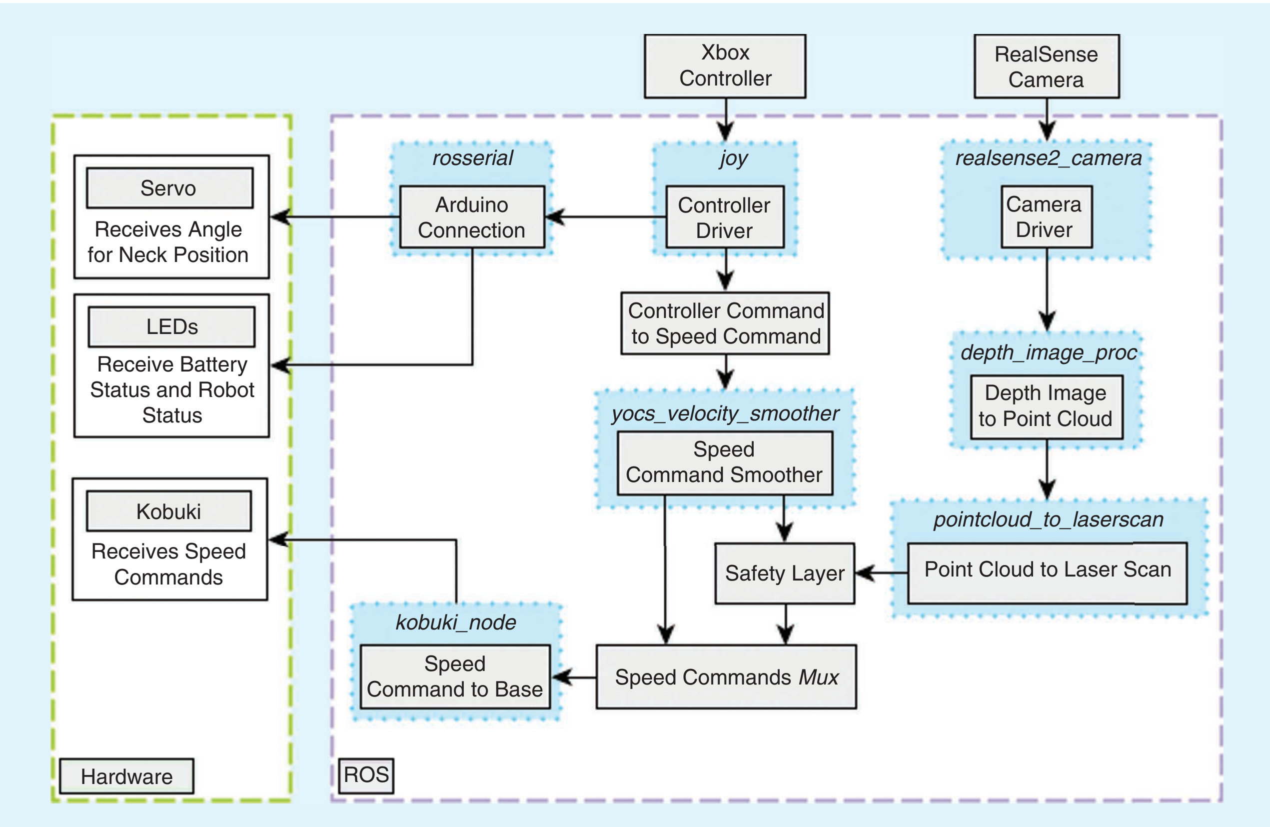

Figure 4. Pudu's software architecture. All of the modules in cyan are ROS packages. LEDs: light-emitting diodes.

the San Juan de Dios Hospital. They are now completing 20 weeks of work based on their initiation into assistance services. A specific Mental Health Care Through the Use of Robotics protocol has been created, providing a theoretical/practical framework for the correct use of robots in mental health areas. It includes aspects such as

1) procedures for handling, transporting, and operating the robot
2) inclusion and exclusion criteria for patients to be treated using the robot
3) ethical and legal aspects of care and telecare
4) aspects of data confidentiality
5) interaction protocols among participants
6) cleaning and disinfection procedures used for the robot.

This protocol, approved by the hospital infection committees and the corresponding clinical service heads, has been used to date without encountering any inconveniences in providing robot-assisted care.

The preliminary results of mental health care have been compiled through nonparticipatory observation, participatory observation, field notes, structured interviews with patients and health-care workers, and anecdotal records of the clinical work carried out with Pudu and its interaction with patients and health-care workers.

The care given was provided by psychointensive practitioners (one), neuropsychologists (one), clinical psychologists (two), neurologists (one), spiritual assistants (one), and communication facilitators through telecare and telepresence (two). All of these types of care were carried out through Pudu's operating modalities, both directly by the professional in charge of the care, as has been the case in psychointensivism and clinical psychology at the Clinical Hospital of the University of Chile, and through a remote teleoperator that enabled functionality and remote connections among professionals, families, and patients, as is the case at the San Juan de Dios Hospital. These two forms of remote control in Pudu were conducted by adapting the functionality and ease of operation to the realities of both health facilities. The attention format is carried out through the tablet located at Pudu's upper end, using available meeting and video calling platforms, such as Zoom and WhatsApp, that are end-to-end encrypted, thus protecting the confidentiality of the communications.

A summary of observations by professionals is as follows:

- Pudu has shown an excellent capacity to move across the areas of intensive and intermediate care in both hospitals. It has an easy approach to the patients' beds, and the patients are completely visible because the inclination of the screen that supports the interaction with the patient can be modified remotely. The distances Pudu has been able to navigate in between the teleoperator and the patient have been from 5 to 30 m, without complications and with visibility, operability, and adequate maintenance of the work network. In addition, the built-in microphone and speaker act as communication facilitators to ensure that the patient and the psychointensivist can hear adequately. It should be noted that, since it began its duties, Pudu has not had any setbacks in movement because it manages to brake or stop when approaching obstacles or when health workers cross its path. It has been able to overcome difficult obstacles in relation to the ventilation

Figure 5. (a)–(e) The current operation of Pudu inside the Clinical Hospital of the University of Chile.

and life support equipment to which the patients are connected and that must not be removed, thus showing its adaptability to the hospital environment.

- Approximately 986 visits have been made using Pudu to patients isolated because of COVID-19 and other non-COVID-19 patients who, for reasons of care standards, were kept in preventive isolation. From these visits, 214 were made by clinical psychology and psychointensive care professionals, 16 were made by other health professionals, and 756 correspond to family telepresence visits.. The patients' ages ranged from 15 to 83 years, without significant differences between genders.
- To date, all of the patients have consented to receive mental/emotional health care from the hospital's psychointensive specialists and psychologists using Pudu, with psychological care aimed at emotional, cognitive, and social assessments as well as sessions that encourage empowerment in these areas. The patients have shown positive attitudes and emotions of curiosity, surprise, joy, and motivation when they meet Pudu. They also express happiness when they observe, through the robot's tablet, the faces of the psychointensivists who treat them (in some cases, for the first time without face masks and face shields) and also of relatives and, in some cases, their spiritual guides. The patients also like being able to have a meeting without the pressure of time constraints. The patients and their families tend to request new encounters with Pudu, expressing high satisfaction and emotional support. In addition, patients also appreciate the fast and private contact that the robot provides with their relatives at home, which is shown in the messages that it subsequently exchanges with them.

The patients have shown positive attitudes and emotions of curiosity, surprise, joy, and motivation when they meet Pudu.

- Pudu awakens positive emotions not only in patients but also in health-care workers. As it moves through the corridors of the hospital, the robot gets staff members to experience feelings of amusement and pleasure. They express comments associated with Pudu's appearance, giving him human characteristics such as, "He's so cute; it's like he's looking at me," or "He's made me nervous; I'd like to hug him." They also approach or follow the robot to observe it in more detail, tending to take out their phones to take photos or selfies next to it (see Figure 5). Most of the responses Pudu has evoked are positive, associated mostly with the fact that it is an "excellent response to the psychological needs of our patients," as expressed by a staff member when he first met the robot.
- It should be noted that the professionals who operate Pudu have also experienced positive emotions during the time that Pudu has accompanied and assisted them in their psychological telecare work because using the robot has made it possible to extend patient-care time to an average of 45 min. The amount of time previously allotted for psychological care with patients in isolation due to COVID-19 had been no more than 10 min on average, given the exponential increase in the risk of contagion in relation to the time of direct exposure. In addition, actually seeing how positively Pudu affects the hospital work environment with its presence also generates personal satisfaction and helps sustain motivation for professionals and operators.

Future Plans

The development of Pudu, a social robot that performs in a hospital context during this period of the COVID-19 pandemic, has generated high expectations among professionals, patients, officials, and the general public. It has delivered the psychological, neuropsychological, and emotional teleassistance for which it was designed and approved in spades, even exceeding the expectations of the team that created the project, achieving a great number of patient visits while maintaining the quality and professionalism of prepandemic times.

Because it is a device that is easy to use, versatile, and made of materials that allow the maintaining of adequate hygiene for intrahospital activities, it is possible to replicate its use in many health-care settings, such as high- and low-complexity hospitals, clinics, family and mental health centers, and residential homes for the elderly because the robots' operability requires minimal learning by users; thus, the possibilities of care are limited only by the availability of professionals.

The characteristics of Pudu have opened up countless possibilities for the robot to contribute to health activities, both in the hospital and in the community. Pudu is already recognized in the corridors and wards of hospitals as a support for mental health care by the hospital community, which will allow it to continue to function even in postpandemic times under the modalities described in this article. We have already identified areas where the use of robotics, specifically the use of Pudu, can make a great contribution, such as in health care, evaluation of care, and neurocognitive therapies for elderly people with cognitive impairment. Other possible functions are the accompaniment and protection of dependent elderly people and assistance and telecontacts with boys and girls during long-term hospitalizations, which will be a great advance with regard to the use of robotics in health, especially in its contributions to treatments for restoring and maintaining mental health.

Conclusions

This article described the design and development of Pudu, a telepresence robot devised to provide mental and emotional health care to COVID-19 patients in isolation. The robot was designed, built, tested, and deployed in just eight weeks, mostly during an intensive quarantine in the city of Santiago. The three key aspects of this achievement are 1) an interdisciplinary team composed of neurologists, psychointensivists, engineers, and designers who knew the specific needs to be filled and had the technical means to fill them; 2) the high commitment of the development team composed of students, most of them members of our IEEE RAS SBC, who, at the same time, were taking online classes during their fall academic semester; and 3) the use of off-the-shelf devices and ROS packages, which allowed for fast implementation of the robot. Two Pudu robots are in use in two Chilean hospitals. To regulate their use for providing mental and emotional health care to patients in ICUs, a specific protocol was created.

The preliminary results show that the use of robots is effective for providing mental health care to isolated COVID-19 patients. The patients not only accept receiving care with use of the robot; they also like it. In addition, the records of the clinical psychologists using the robots show that the patients' attention spans have increased to an average of 45 min. Moreover, patients, clinical psychologists, and other health-care workers are happy to have the robots working close by because the Pudu robots generate positive emotions in the humans around them.

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